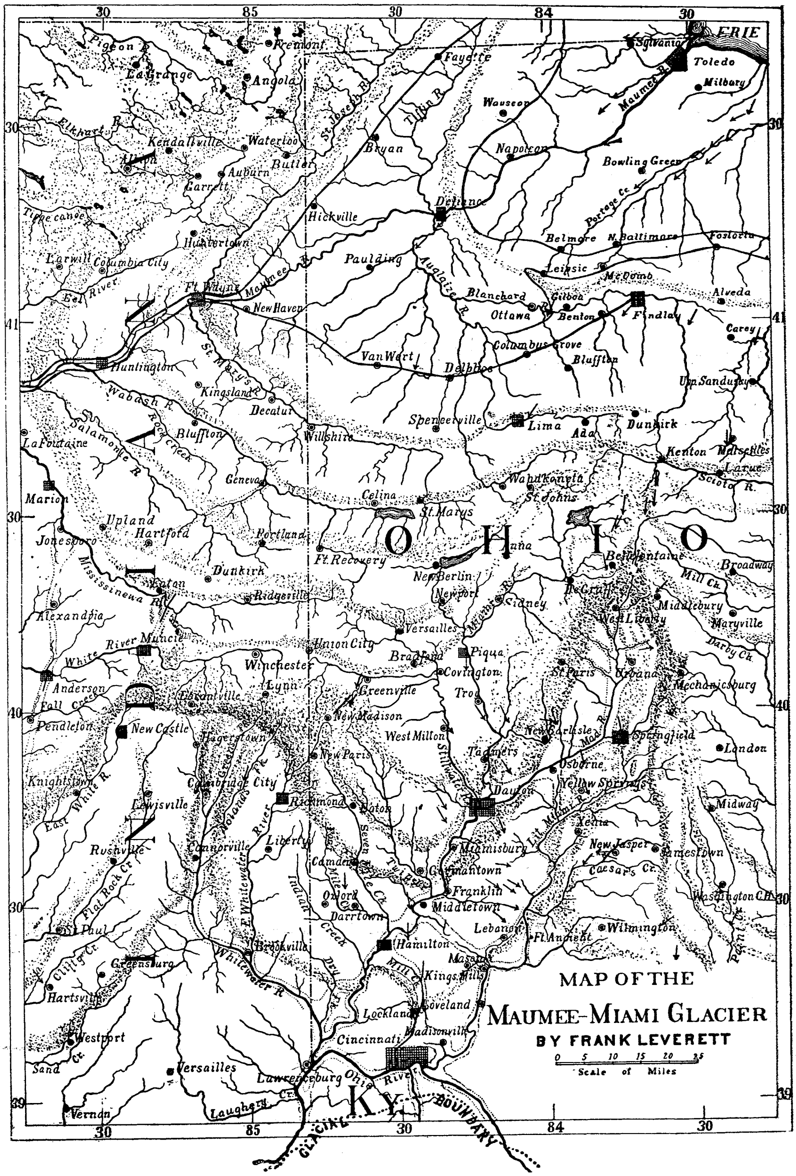
THE GLACIAL SUCCESSION IN OHIO.

In Ohio, as in other portions of the Mississippi basin, clear and unmistakable evidence of discontinuity in the drift deposition has long been recognized. Whittlesey, Newberry and Orton were among the first to announce the occurrence of buried soils in the North American drift, and they each drew illustrations from Southwestern Ohio. A few years later Professor Chamberlin discovered evidences of late advances in which the outline of the ice-sheet was very different from that of the glacial boundary. He also observed that the aspect of the drift is much fresher than in the outlying earlier drift. He further noted the evidence of valley erosion of considerable amount effected in the interval between the formation of two moraines, or more accurately two sets of moraines, in Western Ohio, the oldest of which is much younger than the earliest drift sheet, as will be seen below. My own studies, carried on under the direction of Professor Chamberlin, have brought out more fully the nature and value of these and other intervals which exist in that region. No less than nine of the twelve criteria for discrimination between glacial epochs set forth by Professor Salisbury in the opening number of this Journal have been found, viz.: (1) Buried soils. (2) Buried fossiliferous silts. (3) Differential weathering. (4) Differential subaërial erosion. (5) Excavation of valleys between successive depositions of drift. (6) Changes in the course of ice-currents and in the outline of the ice margin. (7) Superposition of drift of different physical constitution. (8) Varying altitudes of the land. (9) Variations in vigor of ice action. Although the present state of knowledge of the Ohio drift is far from being as complete as one could desire, it seems profitable to review such evidence as throws light upon the value of the several intervals which mark the glacial succession in that state. In the western portion of


MAP OF THE
MAUMEE-MIAMI GLACIER
BY FRANK LEVERETT
0 5 10 15 20 25
Scale of Miles
ERIE
Toledo
Sylvania
Milbury
Fayette
Fremont
Angola
La Grange
Wauseon
Napoleon
Bowling Green
Bryan
Waterloo
Kendallville
Auburn
Butler
Garrett
Hickville
Defiance
Huntertown
Columbia City
Larwill
Paulding
Belmore
N. Baltimore
Fostoria
Leipsic
McComb
Ft. Wayne
New Haven
Blanchard
Gilboa
Ottawa
Benton
Findlay
Alveda
Carey
Columbus Grove
Bluffton
Van Wert
Delphos
Huntington
Kingsland
Decatur
Up. Sandusky
Spencerville
Lima
Ada
Dunkirk
Kenton
La Fontaine
Willshire
Geneva
Larue
Scioto R.
Marion
Celina
St. Marys
Wapakoneta
St. Johns
Upland
Hartford
Jonesboro
Portland
O H I O
Anna
Bellefontaine
Broadway
Ft. Recovery
New Berlin
Dunkirk
Eaton
Ridgeville
Newport
Sidney
De Graff
Middleburg
Alexandria
West Liberty
Maryville
Versailles
Union City
Muncie
White River
Winchester
Bradford
Piqua
Covington
St. Paris
Urbana
Anderson
Lynn
Greenville
Troy
Mechanicsburg
Fall Creek
Pendleton
New Castle
New Madison
West Milton
Springfield
London
Hagerstown
New Paris
Tadmers
Osborne
Knightstown
Cambridge City
Yellow Springs
Lewisville
Richmond
Eaton
Dayton
Midway
Rushville
Connorsville
Liberty
Camden
Miamisburg
Xenia
New Jasper
Jamestown
Caesars Cr.
Germantown
Franklin
Oxford
Darrtown
Middletown
Washington C.H.
St. Paul
Lebanon
Ft. Ancient
Wilmington
Brookville
Hamilton
Mason
Greensburg
Kings Mills
Hartsville
Whitewater R.
Lockland
Loveland
Westport
Madisonville
Cincinnati
Sand Cr.
Versailles
Lawrenceburg
Ohio River
Laughery Cr.
Vernon
KY.
GLACIAL BOUNDARY
Maumee R.
St. Marys R.
Auglaize R.
Wabash R.
Salamonie R.
Mississinewa R.
Miami R.
Mad R.
Lit. Miami R.
Stillwater R.
Mill Ck.
Darby Ck.
Portage Cr.
Tiffin R.
St. Joseph R.
Eel River
Tippecanoe
Elkhart R.
Pigeon R.
Flat Rock Cr.
Clifty Cr.
East White R.
E. Whitewater R.
Indian Creek
Sevenmile Ck.
Twin Ck.
Mill Cr.
Rock Creek
30
85
30
84
30
41
40
39

EXPLANATION OF MAP.— This map was designed for another purpose, and hence includes only a portion of the district under discussion, though it represents the principal features herein discussed. Certain features, not discussed at this time, beach lines, eskers, esker troughs, etc., appear on the map.

The shaded portions of the map represent moraines, the shading being graduated to the strength of the moraine. Arrows indicate the position and bearing of striæ. Continuous lines are used to indicate the beaches of the Maumee basin and the south-western outlet of the lake which formed them. The second beach has not been fully traced, and is therefore incompletely represented. For the same reason the fourth and later beaches are not represented. Esker troughs are bounded by broken lines. The eskers which lie in them are indicated by continuous straight lines. The boundaries between upland and lowland tracts in southern Ohio are indicated by dotted lines. The glacial boundary, indicated by a broken line, appears for a short distance in the vicinity of Cincinnati.

the state there is a more complete and more easily deciphered record of the glacial succession than in the eastern portion, since the later advances there left a portion of the earlier drift uncovered. Our remarks will, therefore, relate chiefly to that district.

The full series of moraines formed by the Great Miami ice lobe, together with portions of the outer moraines of the adjoining East White River lobe on the west, and of the Scioto lobe on the east, are shown on the accompanying map. Outside the outer moraine of these lobes there is a glaciated district extending southward beyond the limits of the map in the main, its southern margin being the glacial boundary which lies fifteen to forty miles south from this moraine. That a long interval elapsed between the deposition of this outlying drift sheet and the formation of the outermost frontal moraine is shown below. Attention is called to it at this point, since it furnishes a convenient landmark in our discussion. The drift to the north of this moraine will be called, for convenience, by the general term, the later drift, while that to the south will be called the earlier drift. Both drifts have a somewhat complex history, and will be subdivided further on.

The earlier drift. For a few miles back from the glacial boundary in Northern Kentucky and in the hilly districts of

Highland, Adams and Brown counties, Ohio, there is a discontinuous or patchy deposit of drift, consisting in places only of scattering bowlders. In other places it consists of a clayey or sandy deposit, in which a few erratics are imbedded. In still others, notably at Split Rock and along Middle creek, west of Burlington, Kentucky, it consists of cemented coarse gravel. Only occasionally in the border portion is there a deposit of thoroughly commingled drift or typical till such as characterizes the thicker drift sheet immediately north. The attenuation seems due more largely to original deposition than to subsequent erosion.

Over the greater part of this earlier drift district back from the attenuated border one finds a nearly continuous deposit of till ranging from a few feet up to one hundred feet or more in thickness. It displays little or no aggregation in morainic knolls or ridges. The greatest thickness is found in filled-up valleys or in depressions, though the uplands in places carry as much as fifty feet of drift. Where less than twenty feet in thickness this drift sheet consists in the main of a yellow till. Where the drift has greater thickness a blue till is commonly found beneath the yellow. The blue till abounds in joints or irregular fissures filled with yellow or oxidized clay, a feature which is rare in the later drift sheet, and may, perhaps, constitute an important line of evidence as to the age. Both the yellow and the blue till are harder than those of the newer drift. The indurated character of this earliest drift sheet is apparently due to a partial cementation with lime, the drift being highly charged with a calcareous rock flour, a glacial grist.

The earlier drift seems to have been deposited in this district without great abrasion of the rock surface. No striæ have been found, though repeated search was made for them. (In districts further west striæ are occasionally found beneath the earlier drift). Between the blue till and the underlying rock there are frequent exposures of a few feet of earthy material having the appearance of residuary clay, or, if this be absent, a very rotten rock surface is usually found. In one village (Mt. Oreb) well

sections are reported to have passed through a black mucky clay, probably a preglacial soil, immediately beneath the blue till and a few feet above the rock surface. This feeble abrasion is thought to be due to lack of vigor in the ice-movement. The attenuated border is apparently due to the same lack of vigor and to a comparatively short occupancy of the region by the ice-sheet. The lack of vigor in this earlier invasion is in striking contrast with the vigor of the invasion which produced the outer moraine of the Miami and Scioto lobes, there being numerous exposures of striation in the district immediately north of that moraine, while the moraine itself bears evidence that the ice-sheet had great shoving power.

There is a possibility that this earlier drift sheet embraces two distinct periods of deposition. Evidence in support of this view is cited by Professor Orton in his report on Clermont county, Ohio (the county bordering the Ohio river just above Cincinnati), viz., that a buried soil and deposit of bog iron occur at the junction between the yellow and blue tills. From Professor Orton's account it would appear that no marked oxidation of the surface of the underlying blue till had occurred before the yellow till was deposited. We infer from this that the interval of deglaciation may have been comparatively brief, though it is possible that swampy conditions, such as prevail in the production of bog iron, prevented oxidation during a prolonged period. Inasmuch as Professor Orton is a careful observer and cautious writer, I do not feel free to question the evidence he cites, but my examinations in this district have not confirmed his evidence, so far as the location of the soil bed at this particular horizon is concerned. I have found testimony as to the occurrence of buried wood at or near this horizon, but not of soil beds. Possibly Professor Orton considers the occurrence of wood good evidence of an old land surface, but in view of the fact that wood may be incorporated in the drift as a part of the glacial debris I have not thought this a sure evidence. In the lists given in the Ohio reports, Dr. Newberry cites instances of wood to prove the existence of a "forest bed," and forest

bed and soil are terms which are used interchangeably in the Ohio Geological Reports. It ought also to be stated in this connection that a few miles to the north a buried soil occurs beneath the till, but it lies within the district covered by a later invasion of the ice, and the horizon is, I am convinced, above that of the one in question. There is also a soil above the yellow till of this earlier drift sheet which is buried by a silt deposit, as described below. I feel, therefore, that it is necessary to refer to different horizons the instances that have been reported from south-western Ohio.

Deglaciation interval with development of a soil attended by oxidation, leaching and erosion of the earlier drift sheet. Except where erosion has removed it a capping of silt several feet in thickness is found upon the surface of this till sheet. It is clearly of much later age than the till, being separated from it by a sufficient interval for the development of a soil, and for a large amount of oxidization and leaching and erosion. This silt is discussed below.

The soil which was developed on this till sheet does not commonly show a black color, though exposures of such a soil color are met with in all parts of the district outside the outer moraine. The evidence of a land surface is more generally found in the deep brown color, and weathering or soil-producing disintegration of the upper part of the till. The deep brown changes gradually below to the ordinary yellow color of oxidized till, but at top it terminates abruptly at the base of the overlying silt. The color of the silt being much lighter than that of this brown soil the contrast is very marked. The deep brown color extends usually to a depth of two feet or more, while discoloration extends to six or eight feet. The amount of discoloration is somewhat greater than is commonly found at the present surface of the newer drift. Repeated comparisons of the soil in the two districts lead to the conviction that this older drift sheet had been exposed as a land surface for a longer time before the silt was laid upon it than has the outer moraine of the newer drift up to the present date. The same conclusion is reached

upon comparing the amount of leaching in the two districts. In the earlier drift sheet it is rare to get a response with acid within six to eight feet of the surface, whereas in the newer drift the leaching has seldom been carried to so great a depth as six feet. It seems clear from the position and relations of this old surface that the leaching took place before its burial.

Concerning the amount of valley erosion accomplished in south-western Ohio during this interval no conclusion was reached. Sufficient time was not given to the study of the region to successfully eliminate the effects of post-glacial erosion and of erosion accomplished between the deposition of the silt and the invasion which produced the older moraine of the later drift. In eastern Indiana, however, there are exceptionally favorable conditions for determining the amount of erosion accomplished between the deposition of the earlier and later drift sheets, and it is believed that data of some importance can be furnished. Near the head waters of the Whitewater river there is a district covered by a thick deposit of drift. We may judge from wells made on interfluvial tracts that the level of the rock surface in that region is no higher than the valley bottoms of the several headwater tributaries of West Whitewater, and these valleys are, therefore, simply channels cut in the drift. The evidence all opposes the view that the ridges and valleys are in any way dependent upon preglacial erosion. The valleys along these headwater tributaries of the West Whitewater (Noland's fork, Green's fork, and West fork) are conspicuous for their size, their width being one-fourth to one-half mile or more and their depth sixty to one hundred feet. A similar broad valley is occupied by the headwaters of East Whitewater, though this stream has, since the later ice-invasion, cut a narrow gorge down into the rock strata.

This district of eroded drift was overridden by the western edge of the Miami and the eastern edge of the East White River lobe of the later incursion, but it so happens that the amount of drift deposited does not greatly conceal the outlines of these old valleys, the general thickness of the later drift sheet in this region

being not more than thirty to forty feet. The outer moraine of the East White River lobe, after following an upland tract west of the West Whitewater northward for some distance, descends, near Cambridge City, into the valley of the West fork of West Whitewater, and after crossing this valley rises near Hagerstown onto elevated upland. The outer moraine of the Miami lobe also, in crossing Noland's fork, south-east of Cambridge City, descends into and is developed in the valley as well as on the bordering ridges. That the valleys were formed previous to the deposition of this moraine, there can be no doubt, and being made entirely in the drift, as noted above, they show clearly that their excavation must be confined to the interval between the deposition of the earliest drift sheet and that of this moraine. The amount of erosion is several times as great as that accomplished by the streams that have traversed this valley since the moraine was laid down. The size of the streams which formed them constitutes an important factor in determining the time required in this excavation. That these interglacial streams were not much larger than those now traversing this region, seems probable from the fact that within a few miles north from the sources of the present streams, the general slope of the country becomes northward, so that drainage would naturally be in that direction, instead of southward along the Whitewater. The erosion here displayed seems, therefore, to indicate the lapse of a longer interval between the deposition of the earliest drift sheet and that of the outer moraine of the later drift, than the time that has elapsed since the formation of that moraine. How much of this interval preceded the silt deposition, it is difficult to determine, because the outer moraine has concealed the silt. Light upon this question should be obtained upon careful study of the lower portion of the Whitewater valley and of other valleys lying within the silt-covered district and outside the moraine, but this line of study has not yet been undertaken.

Depression accompanied by silt deposition. The silt which is found on the upland outside this moraine, has been discussed at

some length, in a recent paper.[1] It need, therefore, be but briefly touched upon here. It is there shown that it forms a practically continuous sheet over the southern portion of the glaciated district in Ohio and Indiana, and extends to an undetermined distance over the unglaciated districts of Ohio. It also appears on the uplands in Kentucky, south-west of Cincinnati, and may appear further east in that state. It has been found along the margin of the glaciated district in Ohio as far north-east as the vicinity of Newark, but has not been observed farther north and east.

The thickness of this silt decreases in passing southward, especially on the interfluvial tracts of south-western Ohio and south-eastern Indiana, a fact which seems to indicate that its source was from the north rather than from flooded conditions of the Ohio river. From evidence gathered in the upper Mississippi region, it is thought to be the correlative of a sheet of glacial drift not exposed to view in these states, or at least not yet discovered. Its thickness in the northern part of the district, next to the outer moraine of the newer drift, is four to six feet or more while on the borders of the Ohio river it scarcely exceeds three feet, and in places is two feet or less. Wherever examined it is found to be thoroughly leached. This fact is thought to be of importance in showing great age, especially on the theory of the glacial origin of the silt, since glacial silts, as well as till, in regions underlain as this region is by limestone, contain a large amount of calcareous material.

The amount of depression involved in this subsidence is difficult to determine. As yet such data as have been discovered bearing upon the altitude of the land, either previous to or during the depression, are not precise, though it seems probable that the altitude was several hundred feet lower at the maximum of depression than at the present time, while before the depression the drainage appears to have been good, and we may suppose that the altitude was not much lower than at the present time.

[1] "On the Significance of the White Clays of the Ohio Region." American Geologist, July, 1892.

Re-elevation of the land. Between the deposition of this silt and the formation of the outer moraine of the later drift, the altitude appears to have become about as great as at the present, since, as shown below, the gravels deposited at that time along valleys leading away from the ice margin bear witness of vigorous drainage.

Outer moraine of the later drift. Since the position of this moraine is indicated on the accompanying map, it need not be outlined. It should, however, be stated that this moraine is overridden by a later one a few miles east of Hillsboro, Ohio, and has not been recognized in the eastern part of the State. The moraine consists of a ridge of drift one to two miles or more in width, standing, as a rule, but twenty to forty feet above the outer border plain. Its surface is gently undulating, there being but a few sharp knolls or ridges, such as characterize the surface of a later series of moraines described below. It is composed mainly of till, though gravel deposits are not infrequent, either in the low knolls or in beds or pockets incorporated in the body of the drift.

Striæ are numerous in the district immediately north of this moraine, and since the usual bearing is toward the moraine and not toward the glacial boundary, it seems evident that they were produced at the time of the later invasion. Some striæ near Cambridge City, Indiana, appear to be out of harmony with the ice-movement of the later invasion, and may, therefore, be older.

The older drift was but partially removed by this later invasion, and it is frequently encountered in wells and exposed in bluffs of streams. It is harder and dryer than the newer drift. In a few places, notably at Marshall and Martinsville, in Highland county, and in the vicinity of Wilmington, in Clinton county, a black soil is found at the base of the newer drift. I have seen it only at Wilmington, but Prof. Orton, in his report on Highland county, calls attention to its occurrence at Marshall, and I was told by well diggers of its occurrence in Martinsville. In Wilmington it is exposed in a railway cutting near the public school building, in the west part of the village. It consists

of black muck, several inches in thickness, overlain by till, and underlain by a yellowish sandy clay. The exposure only extends a foot or so beneath the muck, hence but little is known as to the character at this point of the underlying drift sheet. Dr. Welch, of Wilmington, has found pieces of coniferous wood imbedded in the soil in this and other exposures in that vicinity. He has preserved one piece which shows beaver cuttings. He has also discovered seeds of various plants imbedded in the muck, some of which now flourish only in higher latitudes. The contents of this muck-bed seem, therefore, to indicate an interglacial climate less genial than the present.

In his report on Montgomery county, Ohio, Professor Orton described a buried peat-bed exposed in the bluff of Twin creek, near Germantown. This peat contains the berries and fine twigs of cedar. At the time of Professor Orton's visit, in 1869, the peat was exposed for a distance of forty rods, and had a thickness of twelve to twenty feet. It was underlain by a bed of gravel. At the time of my visit, in 1889, its exposed thickness above the creek bed was about eight feet. It would seem, therefore, that the peat deposit has a somewhat lower altitude where now exposed than where Professor Orton saw it. Professor G. F. Wright, who has also seen the peat-bed, has suggested (Bull. U. S. Geol. Survey, No. 58, pp. 96-97) that it occupies a large kettle-hole, and that the higher portions of the peat-bed were near the rim. This peat-bed is overlain to a depth of 90 to 100 feet by a fresh-looking drift, mainly till, and evidently of the newer drift series. This locality is north of a later moraine than the one under discussion. It is not known whether the peat was accumulated during an interval of deglaciation between the formation of that moraine and the later one, or at an earlier time. The later interval seems to have been sufficiently protracted for the accumulation of this amount of peat.

Several wells in the east part of Wilmington have passed through a fossiliferous silt between the newer till and an older drift-sheet at a depth of about thirty feet. A few minute gasteropod shells obtained from this silt by Dr. Welch await specific

determination. None of them exceed one-sixth of an inch in diameter. Professor Chamberlin reports having observed a bed containing molluscan shells between the newer and older till-sheets at Greensburg, Indiana. (See Third Annual Report U. S. Geol. Survey, p. 333). Positive evidence is wanting as to whether these fossiliferous silts are of the same age as the silts which cover the district outside the moraine, but they appear to have about the same horizon. No fossils have been found in the silts outside the moraine. It seems not improbable, however, that if originally present their exposed situation is such that the fossils may have been dissolved and removed by leaching.

In the case of streams leading southward from this region of newer drift, careful discrimination is necessary to decide the age of terraces. The coarse, gravelly terraces of the Little Miami valley are referred to the stage when the outer moraine was formed. This valley carried a larger volume of water at that time than in later stages of glaciation, because it was more favorably situated for receiving glacial waters. The Great Miami valley was apparently flooded as much during later stages as at this time, and its gravels are largely of the age of the later moraines. The Little Miami gravels are made up, in large part, of coarse material as far down as the mouth of the stream, pebbles two to four inches in diameter being common. The coarseness of the material testifies to a fair gradient, presumably as great as the present altitude of the country affords. The gravels rise to a height of but fifty to one hundred feet above the present stream, and are near the bottom of the valley trench, for the uplands bordering this stream stand 300 feet or more above its bed. The flood stages, though characterized by a much more vigorous drainage than that which obtained while the silt was being deposited on the bordering uplands, did not reach by nearly 200 feet the limit reached by the silt-depositing waters —a fact which seems to be capable of explanation only on the assumption of great orographic movements.

Deglaciation interval in the later drift series. In his reconnaissance of Western Ohio, some ten years ago, Professor Chamber-

lin observed decisive evidences of the lapse of a considerable interval between the formation of a moraine lying east of Mad river, near Urbana and Springfield, and the moraines on either side of it, the moraine on the east being one of the later Scioto moraines, while that on the west is a Miami moraine. This older moraine proves to be the outer moraine of the Miami lobe (see map). While this moraine was being formed the Miami lobe occupied the Mad river drainage area, and the waters from the melting ice-lobe were forced toward the south into the Little Miami valley, passing just east of Springfield. The course is well defined, there being a gravel plain leading south along the east side of this moraine. The altitude of this gravel plain is much greater than that of the immediate bluffs of Mad river valley, but is lower than the water-shed between the Mad river and the Scioto river system, just east of it. It consequently presents somewhat the appearance of a broad irrigating ditch, following the face of a slope at a considerable altitude above the stream. When the ice had retreated from the Mad river basin the drainage of the high country to the east of Mad river soon opened channels directly across this gravel plain and the moraine west of it down to the trough in which the river flows. Similar channels were formed by streams leading down to Mad river from the elevated country west of its basin, and a broad valley was opened along the axis of the trough. When a fresh advance of ice occurred the Miami lobe came nearly down to the Mad river valley from the west and covered the upper portion of the western tributaries. Its moraine, in crossing the interglacial valleys, descends into them, but only partially fills some of them, thus repeating the phenomena of the outer moraine, in the Whitewater valley, as noted above. Similarly, the Scioto lobe trespassed on some of the eastern tributaries of Mad river, and its moraine partially fills the interglacial valleys. It should, perhaps, be stated that these interglacial valleys do not follow preglacial troughs, but instead, have bluffs standing as high as the interfluvial portions of the slopes of the basin. Their excavation began with the retreat of the ice-sheet from the outer Miami

moraine lying east of Mad river. It is difficult to determine the precise amount of excavation accomplished in this interval, since the portions of the valley lying beneath or within the later moraine are partially filled, while the portions lying outside the moraines afforded avenues for the escape of glacial waters, and were probably much enlarged thereby. It seems safe, however, to state that an amount of excavation took place that would require some thousands of years with a drainage system of the size of the present Mad river system, and with a gradient such as the region now affords. It may be added that in regions further west, if our correlations are correct, there are found evidences of the same deglaciation interval, but their discussion does not fall within the scope of this paper.

Main morainic system of later drift. The moraine just referred to (in whose re-entrant angle the Mad river basin lies) belongs to the system mapped and described by Professor Chamberlin, in the Third Annual Report of the U. S. Geol. Survey, as the "Terminal Moraine of the Second Glacial Epoch." As shown by Professor Chamberlin this moraine lies near the glacial boundary in eastern Ohio and north-western Pennsylvania, but farther west it falls short many miles of reaching the glacial boundary. It is a complex system, "constituting a belt rather than a single moraine," there being in places not less than four distinct members. Nearly everywhere in the state it presents a sharply indented surface, a feature which, as suggested by Professor Chamberlin, appears to indicate forceful or vigorous action of the ice-sheet. Its peculiarly sharp contours and their diagnostic characters make it the most conspicuous and distinctive morainic belt in the state. Other moraines, newer as well as older than this morainic system, assume in places the form of smooth ridges or have but gently undulating surface, and hence are less conspicuous features even where they have as great bulk as the individual members of this system. In western Ohio one of the members of this system (the second one of the group) carries on its surface large numbers of crystalline bowlders of Canadian derivation and the remaining members are liberally

supplied. In this respect this morainic system contrasts with all other moraines of Ohio, and especially with the later moraines, there being but few bowlders on their surfaces. In eastern Ohio bowlders are a less conspicuous though not a rare feature. The cause of this unusual abundance of bowlders is an interesting problem and one perhaps not easily solved. It has been suggested by some one, I think it was Mr. McGee, that an unusual abundance of bowlders on the later drift sheets may be an indication that the ice invasion which brought them in was preceded by a long deglaciation interval in the gathering ground, and that the Canadian highlands were scoured afresh after the lapse of sufficient time for ledges to have been seamed and broken under atmospheric influence. The suggestion seems worthy of careful consideration.

The drainage from the ice-sheet was especially vigorous at this time throughout the entire width of the state and as far to the east and west as this morainic system has been identified. The altitude could not well have been less than at present, and may have been somewhat greater.

The later moraines. Between this morainic system and the western end of Lake Erie six more or less distinct moraines occur, which were probably formed in comparatively rapid succession. They each consist usually of a broad ridge one or two miles or more in width, and twenty-five to fifty feet in height. They are each sufficiently bulky to have determined to a large extent the courses of the main drainage lines of northern Ohio (see map) and yet they seldom present a sharply indented or conspicuously broken surface. The overwash aprons and terraces connected with them indicate less rapid discharge of waters than from the earlier moraines, and that too in certain parts of the belts where conditions were very favorable for rapid escape of waters as in the north part of the Scioto basin. It is thought from this feature as well as from the aspect of the morainic ridges themselves, that the ice-sheet had less vigor than when forming earlier moraines. That there was a decrease in altitude seems also highly probable. As noted above, surface bowlders

are of comparatively rare occurrence, being apparently no more plentiful than in the body of the drift. The aspect of this group of moraines is so very different from that of the group which lies outside it, that it is thought not improbable that they are the product of a distinct invasion. No decisive evidence of a long deglaciation interval separating the two groups has, however, been discovered.

Summary. From the facts above presented the following stages of the glacial period seem sustained:

1. A glacial stage during which the ice-sheet extended farther south in western Ohio than in any later stage. This stage will need subdivision in case a buried soil horizon in the midst of its deposits be well substantiated.

2. A long stage of deglaciation marked by development of soil and by attendant oxidation, leaching and erosion of the drift sheet.

3. A stage of silt deposition during which the highest points in south-western Ohio apparently became covered at flood stages. From evidence gathered elsewhere it seems probable that the silt deposition accompanied a glacial stage whose deposits are concealed in this region by later drift sheets.

4. A glacial stage, during which the outermost well-defined frontal moraine was formed. The drift of this stage is concealed in eastern Ohio by the later moraines. Preceding this stage is an interval during which the valleys became opened again to such depth that the main streams, at the time of this later ice invasion, flowed at levels 200 feet or more below the level of the upland silt.

5. A stage of deglaciation of considerable length as indicated by valley excavation.

6. A glacial stage characterized by sharply indented morainic ridges, thought to indicate vigorous action. The ice-sheet reached about to the glacial boundary in eastern Ohio, but fell short many miles of reaching the boundary farther west.

7. A glacial stage characterized by morainic ridges of smooth contour. This stage embraces the final disappearance of

the ice-sheet from Ohio. A deglaciation interval is believed to have preceded this stage, but as yet, decisive evidence in support of this view is not obtained.

We may now profitably review what is known concerning the altitude in each stage:

1. During the earliest advance little of value is known in this region. The scarcity, if not absence, of coarse overwash material seems to indicate feeble drainage and consequent low altitude. It is true that the Split rock and Middle creek conglomerate indicate powerful water action, but if formed as they appear to have been beneath the ice-sheet, they show little as to the altitude of the land.

2. During the period of deglaciation following the deposition of the earliest drift there appear, from the character of the changes effected, to have been fair drainage conditions. We may presume, therefore, that the altitude was not much lower than the present altitude of the region (800–1000 feet A. T.).

3. During the period of silt deposition there can be little doubt that the region stood several hundred feet lower than now.

4. During the formation of the outer moraine of the later drift there were apparently as good drainage conditions as are now afforded in the western Ohio region.

5. During the succeeding deglaciation interval the erosion effected indicates a fair altitude.

6. During the formation of the main morainic system the maximum of elevation was probably reached, there being an especially vigorous drainage at that time, not only in Ohio, but as far to the west as the moraine has been correlated.

7. During the formation of the later moraines there seems to have been a return to low altitude, and still later the Champlain submergence of the coast and St. Lawrence occurred. It is important to note that the Champlain submergence is separated from the submergence which produced the silts of southern Ohio by the periods of high altitude just mentioned, a succession of

periods during which all the Ohio moraines, no less than twelve in number, were being formed.

The decision as to the relative length of the intervals of deglaciation is obviously dependent upon data gathered from the entire glacial field, and should not be rendered in the light of what can be gathered from this limited region.

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